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Device and Method for High-Sensitivity Resolution Detection

The invention concerns a device and a method for high-sensitivity resolution detection of an external variable with the help of acoustic surface waves.

Acoustic surface waves have been in use for the past 30 years for numerous applications in high-frequency technology and sensor technology. A surface wave can interact with external variables, as indicated by A. Wixforth in 1987 (Dissertation of A. Wixforth, University of Hamburg, 1987) for the interaction of surface waves with free charge carriers. In similar manner, according to U.S. 5,235,235 and U.S. 5,325,704, a mass-induced overlay can be detected on the substrate. The damping of a surface wave by mechanical loading by the substrate is described in U.S. 5,767,608 and U.S. 5,838,088. If a variety of surface wave transducers are used to generate various surface waves that pass through a passage of varying length, the location of the mechanical loading can be located by means of the differing delay times. Surface waves can be generated with the help of interdigital transducers (IDT) chiefly on piezoelectric substrates (R.M. White and F.W. Voltmer, Applied Physics Letters 7, pages 314 ff (1965)). Interdigital transducers have two electrodes with finger-type extensions, which

fingers interleave. The propagation qualities of surface waves depend on the finger interval and the phase velocity in the substrate material. According to EP 0 867 826 A2, such an interdigital transducer arrangement can be scanned via an antenna and a transmitter. Surface wave components are used, among other purposes, as dispersive high-frequency filters. To increase the bandwidth, tapped interdigital transducers (TIDT) are used, as described in U.S. 4,908,542, U.S. 4,635,008, U.S. 5,831,492, and U.S. 5,831,494. In tapped interdigital transducers of this type, the finger interval is not constant, it changes along the transducer axis.

It is the task of the within invention to facilitate, with a simple and compact structure, a high-sensitivity resolution measurement of an external variable on a very small spatial scale.

This task is performed with a device for high-sensitivity resolution detection of an external variable, said device having the characteristics of claim 1, or a method for high-sensitivity resolution detection of an external variable, said method having the characteristics of claim 14. Particular embodiments of the device or the method are the subject of sub-claims.

A device according to the invention and a method according to the invention for high-sensitivity resolution detection of the interactions of at least one acoustic surface wave with at least one external variable that influences the acoustic surface wave(s) through interaction in its propagation is characterized by the fact that the acoustic surface wave(s) is/are propagated through the use of at least one specially conceived surface

wave transducer according to input frequency at another position of the area of at least one active surface of the device used, and hence at least one position determination and at least one bit of information about the nature and strength of the pertinent interaction can be obtained via the frequency with which an interaction with the external variable in the transfer function of the surface wave transducer used is determined.

A device according to the invention for high-sensitivity resolution detection of an external variable has, for example, a piezoelectric substrate on which there is at least one device for generating acoustic surface waves through application of an input frequency. The device according to the invention has at least one active surface, positioned in such manner that it can be covered by at least one generating device with an acoustic surface wave for interaction with an external variable. The substrate also has at least one device for receiving the surface waves after passage through the active area. The surface wave generating device is designed in such manner that the propagation of the surface waves in the active surface changes with the input frequency.

In the method according to the invention, an acoustic surface wave is sent in at least one direction through an active area of a substrate and is detected. The active area is brought locally into interaction with an external variable. Various areas of the active surface are covered with surface waves of various frequencies. The change in the parameters of the surface waves through the interaction is detected.

In the device according to the invention and the method according to the invention, the spatial area covered by the surface wave in the active area depends on the

input frequency. If the connection between the input frequency and the propagation range of the surface wave is known, any frequency can be allocated to a propagation range. In this way the local range is imaged in the frequency domain. If a surface wave of specified frequency interacts with an external variable, the parameters of this surface wave change. This change can be detected. When the frequency of the detected surface wave is known, the nature and/or the strength of the interaction can be determined from this change. In the case of a known frequency that determines the propagation range, the location of the interaction can also be determined.

The device according to the invention can be concentrated on a single substrate, e.g., a chip, and it facilitates the measurement of local variables with a resolution in the micrometer range. It can be produced with, for example, appropriate lithographic processes or planar technology. With only one surface generating device, various areas of the active surface can be covered by the surface wave as a result of the frequency dependence. To cover an active area, an individual pair consisting of a surface wave generating device and a surface wave receiving device is sufficient. The structure is thus very easy and inexpensive to produce. It is very easy for measurement technicians to achieve control of the local area in which the surface wave is to propagate through the frequency.

The device according to the invention and the method according to the invention for high-sensitivity resolution detection of an external variable are suitable for all external variables that influence the propagation of the surface wave. The invention has proved

particularly suitable for high-sensitivity detection of local magnetic fields, local illumination, local heating and/or local mechanical stress. The interaction can thereby be effected between the surface wave and free load carriers in the substrate.

A local mechanical stress can be, for example, a pressure applied by a needle-shaped body on the substrate. Another application results from the positioning of micro-components on substrates. The substrate can include a device according to the invention that has an active surface, within which a micro-component is to be positioned on the substrate. The micro-component is then positioned on the substrate and exerts a local mechanical stress. This stress can be detected with the help of the device according to the invention and allows the exact position of the micro-component to be determined or verified. Such an application is particularly advantageous in the case of the integration of mechanical and/or optical and/or electrical components on substrates. For example, the exact position of a micro-mirror on a substrate for opto-electronics can be determined.

The interaction with the external variable leads to a damping of the surface wave or to a change in the acoustic velocity. From the frequency at which this damping or the change in acoustic velocity is detected, a conclusion can be drawn concerning the location of the interaction.

Another advantageous embodiment uses the device according to the invention or the method according to the invention for detection of a local mass-induced overlay. For this purpose a portion of the active surface is functionalized in such manner that it reacts

chemically or physically with external reagents. The mass-induced overlay then likewise changes the propagation qualities of the surface wave.

The frequency-dependent propagation range of the surface waves can be achieved with a device according to the invention, for example through a number of surface transducers that work at various frequencies and are positioned in such manner that they cover various areas of the active surface with surface waves. This can be achieved, for example, with an arrangement of interdigital transducers that have different finger intervals and are thus suited to generating surface waves of varying frequency. Accordingly, a number of interdigital transducers adjusted appropriately are provided on the substrate to receive the surface waves.

The frequency-dependent propagation range of the surface waves can also be established by a surface wave transducer that, depending on a stored high-frequency signal, generates an acoustic surface wave at another position along its axis.

The use of tapped interdigital transducers has proved particularly advantageous. The frequency-determining finger interval of such tapped interdigital transducers changes along the axis of the surface wave transducer. The wavelength of a surface wave is at 0 approximation equal to the quotients of sound velocity and frequency of the surface wave. If at a known sound velocity the frequency input into the tapped interdigital transducer is determined, the surface wave is beamed only in a spatial range in which the interval of the individual fingers of the tapped interdigital transducer accords with the

wavelength. In this way the spatial propagation range of the surface wave can be determined very precisely.

Appropriate tapped interdigital transducers to receive the surface waves after their passage through the active surface lie opposite the tapped interdigital transducer for generating surface waves.

The frequency-determining finger interval of the interdigital transducer can be enlarged linearly or can follow a complicated function in order to achieve a larger or smaller resolution in certain local areas. Lastly, it is also possible to change the finger interval in stages.

In the case of an apparatus with a device for creating surface waves and a corresponding receiving device, the surface wave can be controlled, according to frequency, in one dimension of the propagation range. An apparatus in which two generating devices and two coordinated receiving devices are provided, which generate surfaces of various spatial directions, an active surface can be covered by any generating device. In this way the active surface can be measured two-dimensionally and a two-dimensional local resolution is possible.

Initially a frequency-dependent generating device can be provided to generate the surface waves and the interaction of these surface waves with the external variable at various frequencies can be detected, following which the second generating device generates frequency-dependent surface waves in the same manner.

It is particularly advantageous if the frequency ranges in which the generating devices generate position-dependent surface waves do not overlap. In an individual frequency sweep first one and then the other spatial direction of the active surface can be investigated for an interaction with the external variable.

In a separate embodiment of a method according to the invention or an apparatus according to the invention, provision can be made for wireless radio-scanning of the local interaction with an external variable through the use of at least one additional device.

A particularly advantageous use of the device according to the invention provides for an antenna for inputting a frequency signal into the generating device for generating a surface wave. In this way the generating device can be activated wirelessly. If the receiving device for the surface wave is linked with a transmitting unit., e.g. another antenna, and the signal can thus be scanned wirelessly.

An apparatus of such type can also be scanned completely wirelessly, a great advantage in measurement situations in which no external elements should be introduced. This can be the case in applications that must comply with strict hygiene conditions or if the measurement device or method is to be used in a hard vacuum.

If several devices according to the invention are used at various positions, it is advantageous if the wireless radio transfer also permits the individual devices to be identified. This can be achieved, for example, by appropriate coding methods for identifying the radio scannability of the given device.

The frequency used for radio scanning can thereby correspond directly with the frequency applied to the generating device in order to generate the surface waves in location-dependent manner.

The propagation qualities of the surface wave are changed through interaction with the external variable. For example, the change of phase, intensity, or travel velocity at the input frequency can be evaluated.

With the device according to the invention, for example, a miniature spectrometer or a camera component can be created.

If several surface-wave-generating devices equipped with appropriate receiving devices that send surface waves through the active surface at various angles are provided on an apparatus according to the invention, not only the position but also the shape of the interaction area can be measured. Image processing procedures known from tomography can be used here. Each surface wave transducer pair generates a silhouette shadow of the interaction area. With appropriate image processing software the shape of the interaction area can be generated. This is also advantageous when, for example, the interaction area consists of several non-contiguous individual sub-areas.

A similar effect can be achieved when the interaction area is first covered with a surface wave in one direction and the appropriate signal is recorded. The device is then turned at an angle in the plane of the surface wave without any change in the shape or position of the interaction area in the space. Then an additional detection measurement is performed. The surface waves of the second detection measurement then pass through the

active range in another direction. The same effect as when several transducer pairs are provided on the apparatus to cover the active surface from various directions with surface waves is thereby achieved.

The invention is explained in greater detail by means of preferred embodiments with the help of the attached figures, which show:

Fig. 1 the principal method of functioning of a tapped interdigital transducer,

Fig. 2a the schematic view of a one-dimensional detector according to the invention,

Fig. 2b an example of the frequency-dependent relative phase change upon use of a Fig. 2a embodiment according to the invention,

Fig. 2c the frequency-dependent phase signal of the device according to Fig. 2a with and without interaction,

Fig. 3a another embodiment of the device according to the invention,

Fig. 3b an example of the frequency-dependent transmission for the arrangement according to Fig. 3a, and

Fig. 4 the example of an application of an apparatus according to the invention as illustrated in Fig. 3a.

Fig. 1 illustrates in schematic form a tapped interdigital transducer 4 positioned, for example, on a piezoelectric substrate. It consists of electrodes 5, 7, which have finger-like extensions. In area 3 the finger-like extensions fit into electrodes 5 and 7. Via the feed 2 a voltage can be applied, at a desired frequency, to electrodes 5 and 7. In the example illustrated, interval 8 of the individual fingers changes linearly from position X_o to

position X_n. In a deviation from the illustrated linear change, a complex function of the interval change can also be provided.

Between frequency f_i and wavelength λ_i a surface wave consists in D [sic] approximation of the connection:

$f_i = v_s/\lambda_i$

A surface wave with wavelength λ_i is incited at position X_i at which the finger interval accords exactly with the wavelength. At constant sound velocity v_s, the radiant emission of surface wave 1 is determined through the frequency of the high-frequency signal input via connection 2 at position X_i.

A linear, one-dimension light sensor according to the invention is shown schematically in Fig. 2a. The number 4 designates the interdigital transducer used to generate the surface wave 1, as described in Fig. 1. The number 6 designates the interdigital transducer that serves to receive surface waves 1. Interdigital transducer 6 has in an area 13 engaging finger-like electrodes that serve for detection of surface waves 1. In the area in which the interval of the individual fingers of interdigital transducer 6 accords with the wavelength of the incoming surface wave, a signal with the frequency according to the above-indicated formula is incited. This signal can be tapped at connections 15 and passed on for evaluation.

The number 10 in Fig. 2a shows the area that with the help of interdigital transducer 4 can be covered with frequency-dependent surface waves. This corresponds

to the active area. The number 11 designates a scanning spot with which lighting 9 is generated.

Figures 2b and 2c illustrate signals that can be obtained as follows.

Between the two interdigital transducers 4 and 6, the sensor element is locally illuminated. In the case of a semi-conductor substrate, the incident photons generate free charge carriers in the illuminated area, which in turn interact with surface waves and thereby change the propagation qualities of said surface waves locally. In essence, the propagation qualities of only those surface waves that pass through interaction area 11 are affected. In the transfer function of the two interdigital transducers, this local interaction expresses itself as a definite irruption in the transmitted intensity. Since the position X_j of the generated surface wave depends on the beamed frequency, only one surface wave of specific frequency is influenced by the lighting. A frequency in accord with position X_j that leads to propagation of a surface wave that does not go through interaction area 11 is not influenced.

If the frequency is changed during a measurement cycle, the propagation position of the surface waves changes accordingly from x_o to x_n. The surface wave of varying frequency or wavelength so generated covers, among other things, the interaction area 11.

In Fig. 2c, curve 19 illustrates the phase of the surface waves that can be measured by interdigital transducers 4 and 6 at various frequencies. The switching on of a light 9 leads to an interaction of the surface waves with the lighting in the illuminated

area 11. In the frequency range that corresponds to the illuminated local area, the phase of the surface wave is changed, as shown in curve 21 of Fig. 2c.

Fig. 2b shows the relative phase change generated from curves 19 and 21 of Fig. 2c. In this illustration it is clearly evident that at a frequency of 750 MHz a phase change has taken place through the lighting. The 750 MHz frequency can be converted according to the above-indicated formula to a position, so that in at least one spatial direction the location of the lighting can be determined.

One possible application of such an device is, for example, a spectrometer. A spectrometer is used for the frequency-dependent or wavelength-dependent deflection of light. A conclusion can be drawn from the position deflection with respect to the energy of the beamed light. The position deflection can be determined in a very small local area with the help of the sensor element. From the frequency at which a phase change of the surface wave is detected, a conclusion can be drawn with respect to the position of the light incidence. From the position of the light incidence, on the other hand, a conclusion can be drawn with respect to the frequency or wavelength of the entering light.

Such a sensor element is advantageous in, for example, very small miniaturized experiments. Here the sensor element can also be integrated with a spectrometer element on a substrate structure. If the sensor element is designed to be radio-scannable, the spectrum of a burning gas can, for example, be monitored for environment-protection sensor purposes.

Instead of local lighting 9, a local magnetic field can also be applied, a local heating of the substrate within the active surface 10 can be detected, or a mechanical stress in a very limited spatial range. For example, a micro-touch screen can be created. A local mass-induced overlay can for example be detected through local chemical reactions in an interaction area 11 of active area 10.

Fig. 3a shows another embodiment as an example. It provides for two interdigital transducer pairs 4, 6 and 104, 106. Transducer pair 4, 6 serves to generate and detect surface waves 1, while transducer pair 104, 106 serves to generate and reveal surface waves 101. Both transducer pairs are tapped interdigital transducers, as described with reference to Fig. 1.

Depending on the input frequency, the surface waves are generated at different locations on the corresponding transducer 4, 104. In a frequency-change situation, active area 110 is covered. An interaction area 11, for example a scanning point, can thus be located two-dimensionally. The embodiment illustrated is organized in such manner that the finger intervals of the interdigital transducer 4 do not have an equivalent in the finger intervals of the interdigital transducer 104. The usable frequency ranges of the two interdigital transducers 4, 104 thus do not overlap. If a frequency sweep is made at connection 102 opposite ground connection 123, transducer 4 initially generates a surface wave 1, the position of which changes with the frequency. At a higher frequency that accords with the frequency range of interdigital transducer 104, it generates frequency-dependent surface waves at a different location. Receiver transducers 6 and 106 are

designed accordingly. Their output signal 115 facing ground connection 123 thus corresponds initially to the covering of active field 110 vertically and at higher frequency to the covering of mass area 110 horizontally.

This is shown in Fig. 3b, which shows the relative transmission of the surface waves. The frequency therefore rises from left to right. Curve 125 shows a plateau-like area 127 at lower frequencies, which corresponds to the usable frequency range of transducer 4. The plateau-like area 129 at higher frequencies corresponds to the usable frequency range of transducer 104 or 106. Transmission irruptions 131 and 133 arise through the interaction of the respective surface wave with the external lighting in interaction area 11. A conclusion can then be drawn with respect to the position of scanning point 11. This can occur for example through appropriate computer support.

Fig. 4 shows a computer-supported evaluation of the signal of Fig. 3b. It shows the image-processed signal 140, generated out of the frequency dependency of the relative transmission. Field 142 corresponds to the active area 110 of Fig. 3A. Number 144 clearly shows the receiving of the transmission of the surface waves in the two spatial directions, which accords with scanning spot 11. In this way a camera function can be realized.

Complex shapes of the interaction area can be measured with several transducer pairs or through several measurements in which the direction of the overall device has been changed compared to the interaction area. As in tomographic image processing methods, a evaluation can be made in order to determine the shape of the interaction area.

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For example, an interaction area that consists of several independent sub-areas, e.g. an illumination with several scanning spots, can be measured.

Unlike frequency coding, transducer pairs 4, 104 or 6, 106 for the scanning of the various spatial directions can be separated by reason of the fact that one of the transducer pairs stands at a lesser distance to the other. In this way a time-delay difference that can serve for identification of the transducer pair is created between the different transducer pairs.

Needless to say, a local mass-induced overlay, a local magnetic field, a local mechanical stress, or local heating can be detected in the interaction area 11 if this external variable leads to a change in the propagation qualities of the surface waves.

For example, a very small chemical sensor or a "micro-touch screen" can be created. In the two-dimensional embodiment of Fig. 3a, the element can also be used, for example, in the manner of a quadrant photo diode.

With the device according to the invention or the method according to the invention a very keen high-sensitivity resolution detection of an external variable can thus be achieved with simple construction and with a number of application possibilities. When interdigital transducers are used as surface wave transducers, it is very easy to achieve radio scannability. The relative independence of the operating method from the choice of the input material used moreover permits a multiplicity of conceivable possibilities for use.